AERONAUTICAL SATELLITE COMMUNICATIONS AT TI DATA RATES

M.J. Agan, A.C. Densmore

Jet Propulsion Laboratory, California Institute of Technology
4800 Oak Grove Drive, Mail Stop 238-420
Pasadena, California 91109
Phone: (818) 354-3426 E-mail: agan@bvd.jpl.nasa.gov

ABSTRACT

The Advanced Communications Technology Satellite (ACTS) Broadband Aeronautical Terminal was developed by NASA's Jet Propulsion Laboratory together with various industry/ government partners to investigate high data rate aeronautical applications of ACTS technologies. The terminal was flown on both a C-141 and a Saberliner 50 aircraft. These flight experiments have demonstrated the viability of K/Ka-band aeronautical satellite communications at T1 data rates. Currently available commercial aeronautical satellite communications systems are only capable of achieving data rates on the order of tens of kilobits per second. The broadband terminal, used in conjunction with the ACTS mechanically steerable antenna, has achieve data rates of 768 kilobits per second, while use of an ACTS spot beam antenna will allow data rates up to 2 megabits per second. The use of the K/Ka-band for wideband aeronautical communications has the advantages of spectrum availability and smaller antennas, while eliminating the drawback of this frequency band, rain attenuation, by flying above the clouds the majority of the time. While previous papers on this subject have addressed the terminal design this paper extends the discussion to cover the results of recently concluded flight tests.

INTRODUCTION

Since shortly after the launch of the ACTS in September, 1993 the NASA/JPL developed ACTS Mobile Terminal (AMT) has been conducting land-mobile satellite experiments in conjunction with a variety of industry partners[1]. Much has been learned about this communications channel as a result of these experiments. A natural extension of these experiments was to investigate the K/Ka-band aeronautical communications channel by installing and testing the AMT in an aircraft[3]. Building on these aeronautical experiments the ACTS Broadband Aeronautical Terminal was designed to operate at higher data rates (≥384 kbps vs. 4.8 kbps), and without restrictions on the flight path or aircraft dynamics.

The specific experimental objectives with this terminal are to: (1) demonstrate and characterize the performance of high data rate aeronautical Ka-band communication (2) characterize the propagation effects of the communications channel during take-off, cruise, and landing phases of flight, (3) provide the systems/technology groundwork for an eventual commercial Ka-band aeronautical satellite communication system.

USE OF ACTS

ACTS is an experimental K/Ka-band satellite launched by NASA to explore advanced communication satellite technologies. Positioned in geosynchronous orbit at 100° W longitude, ACTS transmits at 20 GHz and receives at 30 GHz. This experiment required ACTS to operate in the microwave switch mode, in which it behaves as a bent-pipe transponder. The ACTS LA/San Diego spot beam was used to establish the communication link between the fixed terminal at JPL and ACTS. The ACTS one meter diameter mechanically steerable dish antenna was used to establish the link between ACTS and the aircraft.

The use of the ACTS steerable dish distinguishes this experiment from the previous ACTS land mobile and aeronautical mobile experiments in that the previous utilized an ACTS spot beam to illuminate the mobile terminal. The benefit of using the steerable antenna is that it removes the restriction that the flight path be within geographically fixed spot beam contours, allowing the aircraft to fly anywhere in the Western hemisphere. The drawback of using the ACTS steerable antenna is that it is smaller and thus has lower gain than the spot beam antennas, approximately 10 dB less on transmit and 7 dB less receive. This decrease in satellite antenna gain was in part overcome by designing a higher gain antenna on the aircraft.

Use of the ACTS steerable antenna introduces the additional system complexity of requiring the antenna to continuously track the aircraft. The

ACTS steerable antenna has a 3 dB contour of 280 miles, which coupled with a maximum aircraft ground speed of 700 mph, results in a low dynamic tracking requirement. This tracking is accomplished by multiplexing aircraft positioning information (GPS latitude and longitude) with the data stream transmitted from the aircraft to the fixed terminal located at JPL. At the fixed terminal the positioning information is then demultiplexed and transmitted via the public switched telephone network (PSTN) to the ACTS control station, where the ACTS is then commanded to point the steerable antenna to the aircraft location.

TERMINAL DESIGN

A block diagram of the aeronautical mobile terminal is presented in Figure 1. The terminal development leverages off the technologies developed under the AMT project at JPL. As such the RF converter, IF converter, and Data Acquisition System (DAS) subsystems have been adapted from their AMT land mobile designs to operate in the higher dynamic aeronautical environment. The antenna, power amplifier, modem, and video codec were designed/specified specifically for this aeronautical application. The JPL fixed terminal equipment is essentially equivalent to that in the aircraft with the exception of the 2.4 meter ground antenna.

The pre-experiment link budgets for the forward link (JPL fixed terminal-ACTS-aircraft), and the return link (aircraft-ACTS-JPL fixed terminal) are given in Table 1. Not shown in the link budgets for simplicity is the forward link pilot signal. The pilot is transmitted from the fixed terminal to the aircraft as an aid in antenna tracking, Doppler compensation, and link characterization. More detailed descriptions of the subsystems follow.

Video Codecs

The commercial video codec is used to compress/decompress full motion video in real time as well as multiplex the aircraft position information into the data stream which is then passed to the modem, The video codecs are existing (off-the-shelf) codecs. In an effort to select an appropriate video codec for the aeronautical mobile satellite communication environment, codec requirements were specified, an exhaustive survey of video codec manufacturers was performed, and lab trials of three codecs were conducted at JPL. A summary of the codec requirements is given in Table 2. The surveyed video codec manufactures included: Compression Labs, VTEL, NEC, British Telecom, Panasonic, ABL, Hitachi, PictureTel, Mitsubishi, Horizons, UVC, and a variety of compression board manufacturers. A crucial part of this survey involved making qualitative evaluations of the video quality at the data rates of primary interest. After the list of candidates was narrowed, laboratory tests and satellite experiments were performed with the ABL, CLI, and NEC video codecs.

The ideal video codec for aeronautical mobile applications has characteristics that are not necessarily important when the codecs are utilized in their traditional role of fixed site video teleconferencing. The aeronautical mobile satellite communications channel may have periods of signal outage due to aircraft structure shadowing or the antenna tracking keyhole effect (e.g., keyhole is symptomatic of 2-axis tracking mechanisms, when the tracking angle closely approaches one of the mechanisms rotational axes). Signal outages necessarily require the video codec to regain synchronization rapidly when the signal returns. The best outage recovery performance that could be had with existing video codecs was on the order of three seconds after the codec started receiving valid data. Because the mobile satellite communications channel typically has a higher bit error rate than the video codecs were designed to withstand it is critical that the codec degrade gracefully in this environment and recover rapidly. Some video codecs were found to have the undesirable tendency to "hang" or "freeze" in the presence of high bit error rates.

Other required codec features are that the codec be small in size, light in weight, somewhat rugged in construction, and capable of multiplexing multiple external data sources with the compressed video data stream.

In evaluating the codec video quality the performance at data rates from 128 kbps to 384 kbps was deemed to be most important for the mobile SATCOM experimental applications. Most video codecs were found to provide very good quality video at data rates approaching TI (1 ,544 Mbps), but there were significant differences in quality at the data rates of interest. Quality varied primarily in image resolution, but also in motion handling capability. All the video codecs had their own advantages and disadvantages, but on the whole the NEC video codec was determined to be the currently available codec most appropriate for the aeronautical experiments.

The NEC video codec utilizes the ITU-T H.261 standard which was optimized for full-color real-time motion videoconferencing. H.261 is a constant bit rate but variable quality encoding scheme. The algorithm optimizes bandwidth usage by trading-off picture quality against motion, resulting in fast moving objects in the field of view not being as clear as static objects. The NEC audio codec utilized the ITU-T G.728 video conferencing standard which compresses 3.4 kHz of audio into a 16 kbps data stream using Low-Delay Code Excited Linear Prediction (LD-CELP) coding.

Modem

The modem was designed to counteract the peculiarities of the K/Ka-band aeronautical communications channel, including varying frequency offsets, phase noise, and signal outages. BPSK modulation is combined with coherent demodulation, and error correction coding is provided by a concatenated code, a convolutional inner code (rate 1/2, constraint length 7) and a Reed-Solomon outer code (rate 239/256). The modem bit error performance is shown in Figure 2, A bit error rate of 10^{-6} is achieved at an E_b/N_o of 3.0 dB.

Operation at higher bit rates, compared to the AMT, allows the use of coherent differential detection because the high close-in to the carrier phase noise can be tracked out by the wider bandwidth of the tracking loop. The receiver loop parameters had to be optimized to allow for Doppler frequency offsets of up to 30 kHz, with variations up to 900 Hz/see to be tracked. Additionally the synchronization algorithms (carrier, bit, and decoder) had to be optimized to allow recovery synchronization within one second of signal presence. Commquest Technologies, Inc. modified a commercial satellite modem to meet these aeronautical requirements for JPL.

RF Electronics

The IF up/down converter translates between 3.373 and a lower 70 MHz IF at the output/input of the modem. A key function of the IF converter is pilot tracking and Doppler pre-compensation. The down-converted pilot is tracked by a phase-locked loop and used as a frequency reference in the mobile terminal. The loop is capable of tracking out 39 kHz of Doppler varying at 900 Hz/sec. The tracked pilot in the mobile terminal is also processed in analog hardware and mixed with the up-converted data signal from the modem to pre-shift it and offset the Doppler on the return link, The IF converter provides the DAS and antenna subsystems with reports of pilot signal strength for link characterization and antenna pointing operation respectively.

Preceding (or following) the antenna the RF up (down) converter will convert an IF around 3.373 GHz to (from) 30 (20) GHz for transmit (receive) purposes. The RF converter interfaces directly to the antenna on the receive side of the link. On the transmit side the RF converter 30 GHz signal is routed to the traveling wave tube amplifier (TWTA). The TWTA outputs 120 Watts of 30 GHz transmit power. To ensure maximum radiated power and provide the required mechanical flexibility the TWTA is connected to the antenna via low-loss (0.2 dB/ft.) Gore-Tex dielectric waveguide.

Antenna

The high gain aeronautical antenna employs an elevation over azimuth pointing system to allow it to track the satellite while the aircraft is maneuvering. The aeronautical antenna and radome were developed by EMS Technologies, Inc. The antenna design utilizes two slotted waveguide arrays, is mechanically steered in both azimuth and elevation, and allows for mounting on a variety of aircraft. Figures 3 through 5 depict the antenna without the radome. The polarizer in front of each array achieves the required circular polarization.

The antenna radome was designed for low loss at both frequency bands with the mechanical integrity to withstand the aerodynamic loads on a jumbo jet. The radome is shaped with a peak height of 6.7" and a 27.6" diameter; roughly the size of the Sky Radio radome currently flying on United Airlines and Delta Airlines aircraft. Figures 6 through 8 show the antenna with radome installed on the C-141 and Saberliner 50. Antenna installation requires a 3.5" diameter protrusion into the fuselage to allow the necessary signals to pass to and from the antenna.

The antenna is capable of tracking a full 360° in azimuth and -5° to zenith in elevation. The antenna has a transmit gain of 30 dBi and a receive sensitivity (G/T) of O dBi/°K. There exists the capability to transmit up to 120 Watts through the antenna. The actual dimensions of the transmit and receive array apertures, shown clearly in Figure 4, are each approximately 4" x 8", and the arrays are approximately 0.5" thick. The polarizers add another 0.3" to the total antenna thickness. The receive array has 161 elements with an ideal directivity of 30.4 dB at band center. The receive 3 dB beamwidths are 4.0° in azimuth and 7.6° in elevation, respectively. The transmit array has 366 elements with an ideal directivity of 34.1 dB at band center. The transmit 3 dB beamwidths are 2.6° in azimuth and 5.0° in elevation, respectively. Both arrays were designed to have maximum in-band VSWR of 1.3:1 and 1 s-t sidelobe levels below 13 dB.

The antenna tracking mechanism was required to maintain pointing within 0.5 dB of beam peak throughout all phases of flight. The antenna's narrowest beamwidth of 2.6° thus requires fine tracking accuracy as the aircraft turns. The antenna positioner utilizes the elevation-over-azimuth mechanism with a precision of a few hundredths of a degree. This positioner is controlled by a tracking algorithm that utilizes three sources of information, a three-axis inertial rate sensor (IRP), the aircraft Inertial Navigation System (INS), and pilot signal strength feedback from a conical scanning of the beam. The IRP with 50 Hz bandwidth and mounted on the main antenna assembly provides the majority of pointing information for the tracking system, A very low bandwidth (0.5 Hz), small displacement (0.5°) conical scan feedback control system is used to cancel, in the steadystate, and continually adjust to any changes in the three axis inertial sensor offsets and drift rates. The INS is used for satellite acquisition and correction of IRP drift. The overall tracking system accommodates tracking rates up to 60 deg/sec and 30 deg/sec/sec in azimuth, and 30 deg/sec and 15 deg/sec/sec in elevation.

As can be seen in Figures 6 and 7 the antenna is installed on the top of a C-141 fuselage, behind the main wing, where it has a nearly unobstructed view to the geostationary ACTS satellite (1 00° West longitude). The aerodynamic affect of the radome on the aircraft stability was computed and experimentally verified to be negligible on the G 141, especially since the wings are not in the wake of the radome. The wind speed on C-141 was typically about 400 MPH, and overall forces on radorne are about 150 pounds laterally (drag). With the custom radome venting the lifting force on the radome is neutralized to less than about 200 pounds. A similar aerodynamic analysis was performed for the radome installation on the Saberliner shown in Figure 8. Due to the asymmetry of the installation and the air turbulence introduced by the radome on this smaller aircraft the speed was limited to 250 knots to provide the requisite safety margin.

DAS

The DAS performs continuous measurement and recording of a wide array of propagation, communication link, and terminal parameters to aid in the characterization of the communication channel (e. g., pilot and data signal conditions, noise levels, antenna direction, aircraft velocity, pitch, roll, yaw, etc.). The DAS also provides real-time displays of these parameters to aid the experimenters in the aircraft and in the fixed terminal.

EXPERIMENTS

The initial two experiments that have been conducted with the aeronautical terminal are shown in the accompanying Figures 9 and 10. The NASA Ames Research Center flew the terminal in the Kuiper Airborne Observatory (KAO) to transmit imagery from the aircraft for an educational broadcast and to conduct remote tele-science. Rockwell/Collins flew the terminal on Rockwell Saberliner 50 aircraft to demonstrate high data rate transmissions to and from the aircraft. Beyond these two experiments, the next planned experiment is shown in Figure 11.

KAO/ACTS Experiment

JPL, working cooperatively with NASA Ames, conducted a series of ACTS aeronautical experiments on the KAO. These experiments took place from June through October 1995. The JPL developed ACTS Broadband Aeronautical Terminal was installed in the KAO C-141 aircraft to allow the establishment of a full-duplex 768 kbps satellite communications link between the aircraft and the ground, supporting live video and audio transmissions and to extend Internet into the aircraft. A sample of the live video transmitted from the aircraft is shown in Figure 12. The KAO equipment installation is shown in Figure 13. There were four components of this experiment:

1) Television broadcast/interactive classroom - a PBS produced live television broadcast entitled "Live from the Stratosphere". As part of the broadcast, students watching the live video transmitted from the aircraft were able to ask questions via video/voice link to the aircraft.

2) Video downlink to the San Francisco Exploratorium and Adler Planetarium in Chicago.

3) Telescience demonstration of remote control of scientific instruments onboard the KAO via an

extension of Internet connectivity to onboard the aircraft.

4) System Health Monitoring demonstration of a system that remotely monitors scientific instruments onboard the KAO via Internet.

KAO Experiment Results All components of the experiment were successfully accomplished. Live video, audio, and Internet data were transmitted to and from the aircraft while in flight and the live television broadcast was carried on most PBS stations throughout the U.S. The terminal logged approximately 150 hours of in-flight operation over the four month test period, The final antenna configuration achieved overall RMS tracking error of less than 1/2°. The performance estimates of link budgets shown in Table 2 proved to be on the conservative side. For the majority of the flights a full-duplex 512 kbps link was maintained with an aircraft received E_b/N_o in the 15 to 16 dB range and the fixed station received E_b/N_o in the 10 to 11 dB range. These E_b/N_o values indicate that T1 data rates could have been maintained with some link margin. The data rate was maintained at 512 kbps because the T1 line shown in Figure 9 had been originally configured for this rate and would have required new hardware to change the data rate.

The flight tests were not without problems, including satellite configuration errors, equipment failures, and terminal configuration errors. Many of these problems were brought on by the fact that the terminal was installed and reinstalled five separate times on the aircraft due to space and schedule constraints. Once an installation had been debugged the terminal was found to operate quite reliably. Only once during the eight hours of televised flight was an outage experienced, and only of a 5 second duration. This one event is thought to have been a "keyhole" outage - when the direction to the satellite passed very near the positioner azimuth axis (zenith), temporarily requiring greater azimuth angle acceleration than the positioner's capability. The outage occurred during a very steep turn (35° roll angle) just before landing in Southern Texas, where the satellite elevation look angle is about 55".

Rockwell/Collins Experiment

Rockwell International/Collins Corporation Commercial/Government Aeronautical Services and JPL are currently working together on a series of experiments to investigate the feasibility and limitations of airborne Ka-band satellite communications. The initial phase of this experiment was conducted in August 1995 and the second phase will take place in March 1996. This experiment involves the installation of the Broadband Aeronautical Terminal into Rockwell's Saberliner 50 aircraft for a series of demonstration flights. The specific objectives of this experiment are to:

1) Determine the feasibility of high data rate communications, in particular compressed full motion video, to and from an airborne platform under varying weather conditions.

2) Determine the feasibility of slaving the steerable satellite antenna to an onboard aircraft Global Positioning System (GPS) receiver in order to automatically follow the flight path of the aircraft, allowing the highest possible data rate channel for critical applications.

This experiment has applications to both commercial aviation and government airborne services, Commercial airlines wish to offer live video and high bandwidth multimedia services to passengers, but currently do not have the necessary bandwidth capacity to/from the aircraft. Various government entities have mission requirements to transmit and receive real-time video between airborne mobile terminals and fixed earth terminals.

Rockwell Experiment Results The Broadband Aeronautical Terminal was installed on the Saberliner 50 aircraft as shown in Figures 8 and 14 and a series of flight tests were conducted during the month of August 1995. These initial tests were a scaled back version of the ultimate tests that will be performed in March 1996. Four flight tests were conducted in varying weather conditions and the terminal was found to perform quite well during these tests. The flight tests were conducted with the ACTS steerable spot beam fixed pointed at Cedar Rapids, Iowa and flight paths from Nebraska to South Dakota were flown to intersect the spot beam. The system was able to acquire the satellite signal prior to take-off and remain locked during take-off, cruise, and landing, maintaining a full-duplex 64 kbps link the entire time.

The problems encountered during these experiments again were primarily due to debugging the initial installation. Beyond the initial installation problems the only other significant problem was due to overheating of the equipment when the temperature in the aircraft rose to 115° while on the tarmac.

When the Rockwell experiments are continued in March 1996 a higher power TWTA will be installed in the aircraft which will allow the transmission of compressed video to be transmitted to and from the aircraft at data rates approaching T1. This second phase will also utilize the ACTS steerable antenna in the tracking mode thus freeing the aircraft to fly anywhere in the Western hemisphere.

Wildfire Research and Disaster Assessment Experiment

In 1996 NASA Ames and JPL will be installing the Broadband Aeronautical Terminal in either a C-130 or Learjet to perform fire research and assessment during a prescribed burn and an actual wildfire in Southern California as shown in Figure 115.

Airborne sensors that generate imagery of the fire will be uplinked from the burn site and relayed by the ACTS to researchers and disaster assessment managers at various agencies. This "telepresence" can enable experts at the U.S. Forest Service, Federal Emergency Management Agency, Office of Emergency Services, and the California Department of Forestry to direct and/or monitor various phases of the activities at the remote fire site.

The experience gained from merging remote sensing and mobile satellite communications **used** in the management and assessment of the prescribed burn experiment can lead to their application in real-life wildfire situations. Also, the experience gained from this proposed experiment will, hopefully, contribute to a more effective long-term policy of wildfire management, and to improved coordination procedures in more general emergency situations such as hurricanes, floods, volcano eruptions, and oil spills.

SUMMARY

JPL, working with its industry partners, has successfully flight tested a pre-commercial broadband aeronautical terminal and demonstrated new applications and uses of K/Ka-band satellite communications. The data collected during the flight tests will be studied in detail and results made available to any parties interested in the commercialization of the technology. Additional applications will continue to be explored with continued flight tests. Planned commercial satellite systems with which the equipment described in this paper could be utilized include the K/Ka-band systems proposed by Hughes (Spaceway) and Teledesic who are amongst the eleven companies who have filed with the FCC[7].

REFERENCES

[1] K. Dessouky and T. Jedrey, "The ACTS Mobile Terminal", Proceedings 14th AIAA Conference, March 22-26, 1992, Washington, DC.

[2] B. Abbe, and D. Pinck, "AMT Experiment Results", International Mobile Satellite Conference, IMSC'95, June 6-8, Ottawa.

[3] P. Sohn, C. Raquet, R. Reinhart, D. Nakamura, "ACTS Aeronautical Terminal Experiment System Description and Link Analysis", International Mobile Satellite Conference, IMSC'95, June 6-8, Ottawa.

[4] E. Elizondo, J. Balcewicz, A. Stern, O. Regalado, T. Drackett, and S. Chulik, "Operational Satellites Using ACTS Technology," AIAA-94-0939-CP, Proceedings of the 15th International Communications Satellite Systems Conference, February 1994, San Diego.

[5] L. Shameson, J. Brass, J Hanratty, A. Roberts, and S. Wagener, "Satellite Communications Provisions on NASA Ames Instrumented Aircraft Platforms for Earth Science Research/Applications", International Mobile Satellite Conference, IMSC'95, June 6-8, Ottawa.

[6] M. Agan, A. Densmore, "ACTS Broadband Aeronautical Terminal," International Mobile Satellite Conference, IMSC'95, June 6-8, Ottawa.

[7] "Satellite Plan Would Let AT&T Bypass Local Networks - If It's Ever Launched," Wall Street Journal, October 5, 1995, p. A4.

ACKNOWLEDGMENTS

The research described in this paper was carried out by the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.

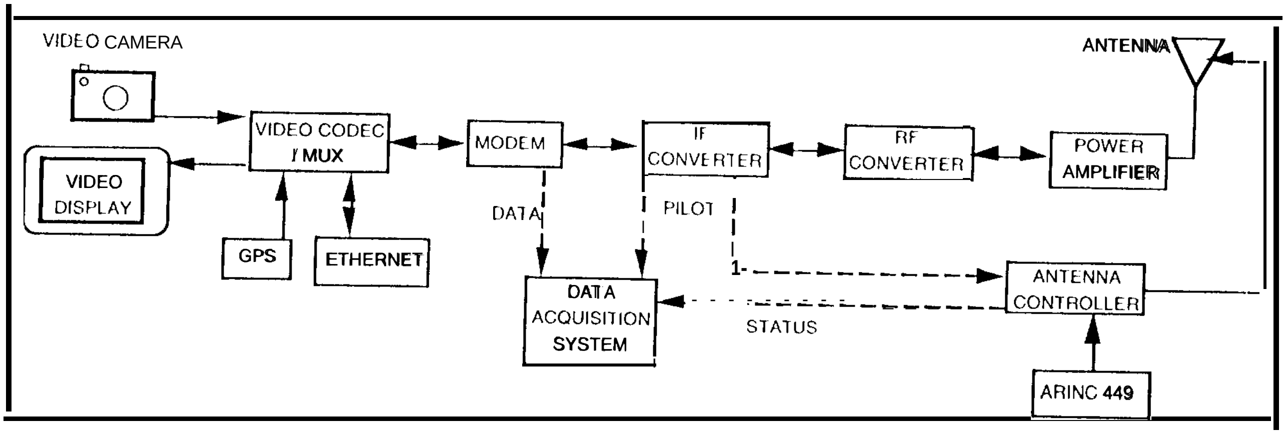

Figure 1 Block Diagram of the Broadband Aeronautical Terminal

Table 1 Link Budgets

RETURN (JPL-TO-ACTS-TO-AIRCRAFT) LINK BUDGET

UPLINK: AIRCRAFT-TO-ACTS

TRANSMITTER PARAMETERS	
TRANSMIT POWER, DBW	20.0
BPF & WG LOSSES, DB	-3.8
ANTENNA GAIN (W/RADOME), DBiC	29.0
EIRP, DBW (NOMINAL)	45.2
POINTING LOSS, DB	-0.5
POL. LOSS: CIRC. W/2DB AXIAL RAT., DB	-4.1
PATH PARAMETERS	
MAX. SPACE LOSS (AT 10° ELEVATION ANGLE), DB	-214.6
(FREQ., GHZ	29.6
RANGE, KM)	42800
ATMOSPHERIC ATTN, DB	-0.4
RECEIVER PARAMETERS	
G/T: STEERABLE BEAM PEAK, DB/K	14.5
POINTING LOSS(EDGE OF BEAM), DB	-0.5
BANDWIDTH, MHZ	900
RECV'D C/NO, DB.HZ	68.3
TRANSPONDER SNR IN, DB	-21.3
LIMITER SUPPRESSION	0.0
TRANSPONDER SNR OUT, DB	-21.3

DOWNLINK: ACTS-TO-JPL

TRANSMITTER PARAMETERS	
EIRP (EOC), DBW	41.1
POINTING LOSS, DB	-0.2
PATH PARAMETERS	
SPACE LOSS, DB	-210.0
(FREQ., GHZ	19.9
RANGE, KM)	38000
ATMOSPHERIC ATTN, DB	-0.5
RECEIVER PARAMETERS	
POLARIZATION LOSS, DB	-0.1
G/T, DB/K	25.7
POINTING LOSS, DB	-0.5
DOWNLINK C/N0, DB.HZ	84.1
OVERALL C/N0, DB.HZ	68.2
REQ'D EB/N0 (AWGN--SIMULATION), DB	3.0
MODEM IMPLEMENT. LOSS, DB	1.0
LOSS DUE TO FREQ. OFFSETS/DOP.,DB	1.0
REQUIRED EB/No, DB	5.0
LOSS DUE TO ACTS PHASE NOISE,DB	1.0
DATA RATE, KBPS	384
REQ'D EFFECTIVE C/N0,DB.HZ	61.8
HARDWARE PERFORMANCE MARGIN, DB	6.3

FORWARD (JPL-TO-ACTS-TO-AIRCRAFT) LINK BUDGET

UPLINK: JPL-TO-ACTS

TRANSMITTER PARAMETERS	
TRANSMIT POWER, DBW	16.7
WAVEGUIDE LOSS, DB	.85
ANTENNA GAIN, DBi	54.7
AVAILABLE EIRP DBW	62.9
PERCENTAGE OF EIRP IN DATA SIGNAL %	91.0
EIRP, DBW	62.5
POINTING LOSS, DB	-0.8
PATH PARAMETERS	
SPACE LOSS, DB	-213.5
(FREQ GHZ/MHZ	29,6
ACTUAL RANGE KM)	38000.0
ATMOSPHERIC ATTN, DB	-0.4
RECEIVER PARAMETERS	
POLARIZATION LOSS DB	[illegible]
G/T (EOC), DB/K	17.9
POINTING LOSS, DB	-0.1
BANDWIDTH, MHZ	9000
RECV'D C/NO, DB HZ	94.1
TRANSPONDER SNR IN, DB	4.5
LIMITER SUPPRESSION, DB	-0.2
HARDLIMITER SNR OUT, DB	4.3

DOWNLINK: ACTS-TO-AIRCRAFT

TRANSMITTER PARAMETERS	
STEERABLE BEAM MINIMUM PEAK EIRP	55.7
EIRP, DBW	54.0
POINTING LOSS (EDGE OF BEAM), DB	-0.5
PATH PARAMETERS	
MAX SPACE LOSS (10° ELEVATION), DB	-211.1
(FREQ GHZ	19.9
MAX RANGE (AT 10° ELEVATION ANGLE), KM	42800.0
ATMOSPHERIC ATTN, DB	-0.5
RECEIVER PARAMETERS	
POL LOSS CIRCULAR W/2DB AXIAL RAT., DB	-4.1
G/T (W/RADOME) DB/K	0.0
POINTING LOSS, DB	-0.5
DOWNLINK C/N0, DB HZ	65.9
OVERALL C/N0, DB HZ	65.9
REQ'D EB/N0 (AWGN--SIMULATION), DB	3.0
MODEM IMPLEMENT. LOSS, DB	1.0
LOSS DUE TO FREQ OFFSETS/DOP DB	1.0
REQUIRED EB/N0, DB	5.0
LOSS DUE TO ACTS PHASE NOISE, DB	1.0
DATA RATE KBPS	384.0
REQ'D EFFECTIVE C/N0, DB HZ	61.8
PERFORMANCE MARGIN DB	4.0

Table 2 Video Codec Specifications

weight	<40 lbs.
height	<7"
compressed video rates	56 kbps to 2.048 Mbps
compressed audio rates	16 kbps to 64 kbps
image quality	high compressed image quality at all data rates
voice quality	high compressed voice quality at all data rates
power consumption	<300 Watts
BER performance	operate without degradation at 10^{-6}
operating temperature	typical of aircraft environment
operating humidity	typical of aircraft environment
clocking	independent transmit and receive data rates
broadcast capability	must be capable of transmitting while the receive is disabled, must be capable of receiving while the transmit is disabled
RS232 data ports,	minimum of two ports
video format	NTSC
line interface	RS449 line interface
mounting scheme	rack mount hardware required

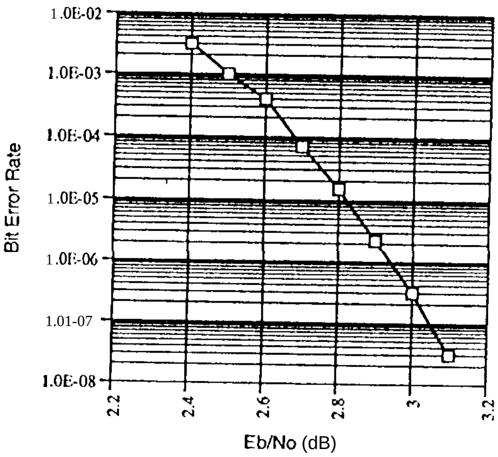

Figure 2 Modem BER Performance

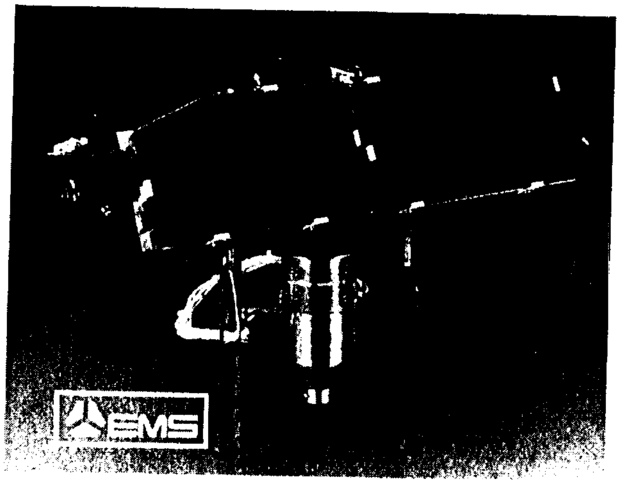

Figure 3 Slotted Waveguide Antenna

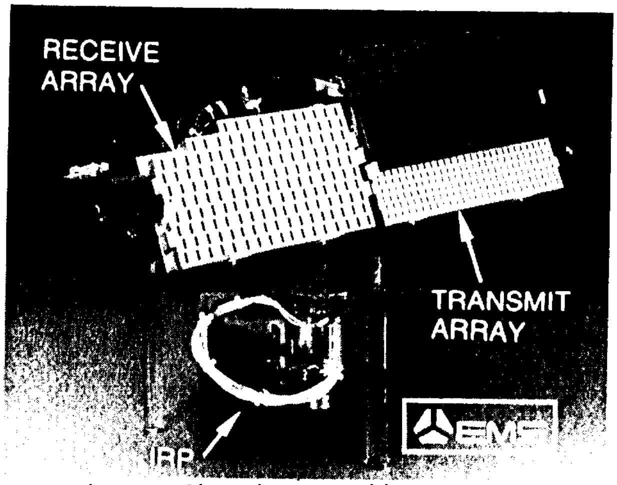

Figure 4 Slotted Waveguide Antenna
(Polarizers Removed)

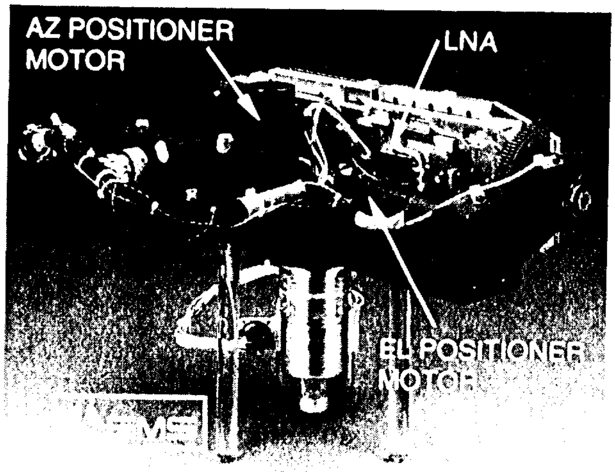

Figure 5 Slotted Waveguide Antenna
(Rear View)

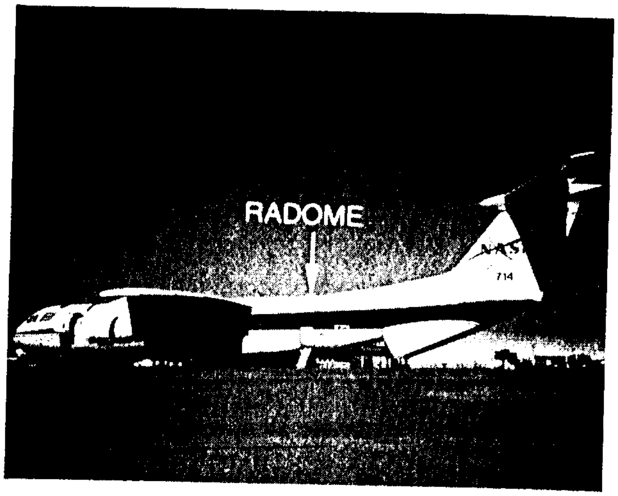

Figure 6 Antenna Radome on KAO C-141

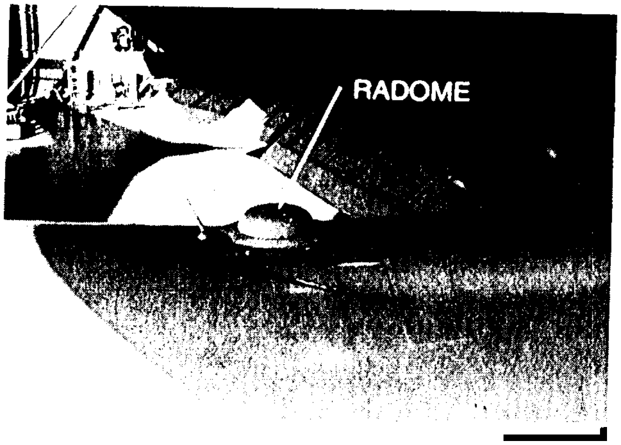

Figure 7 Antenna Radome on KAOc.141

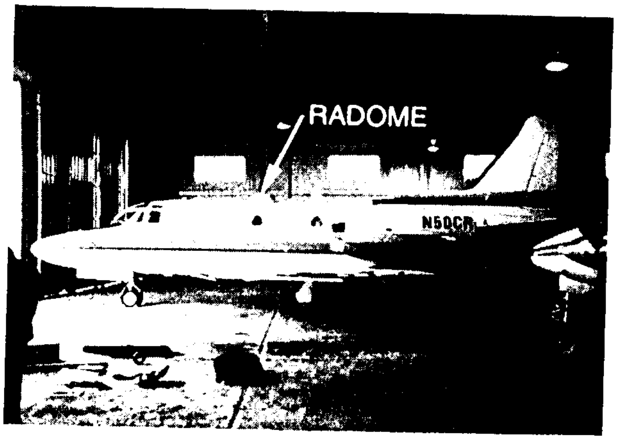

Figure 8 Radome on Rockwell Saberliner 50

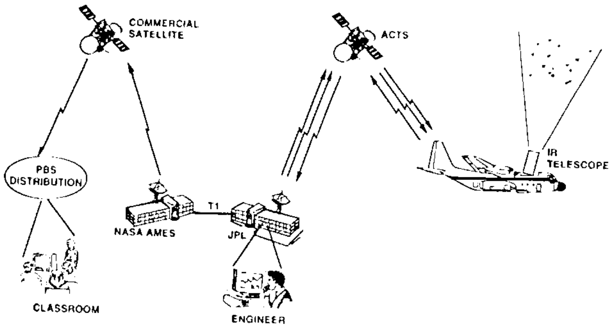

Figure 9 KAO Experiment

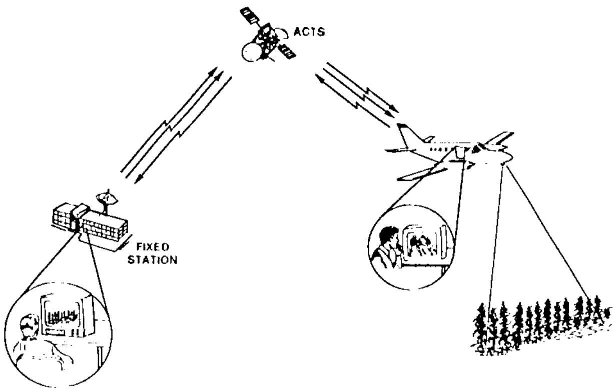

Figure 10 Rockwell/Collins Experiment

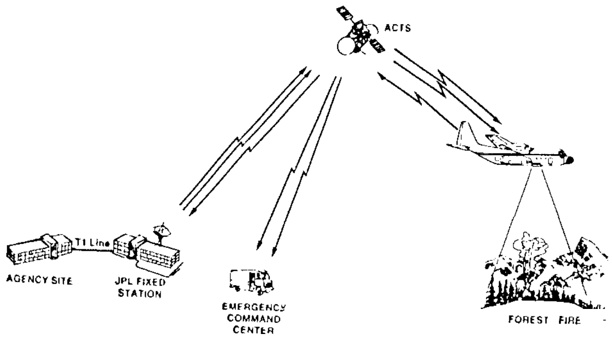

Figure 11 Wildfire Research and Disaster Assessment Experiment

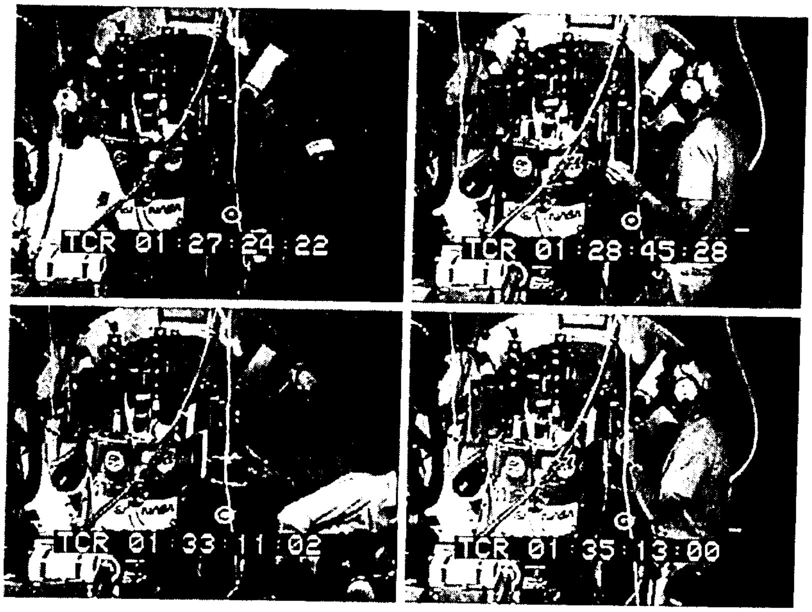

Figure 12 Video Frames Transmitted From KAO in Flight

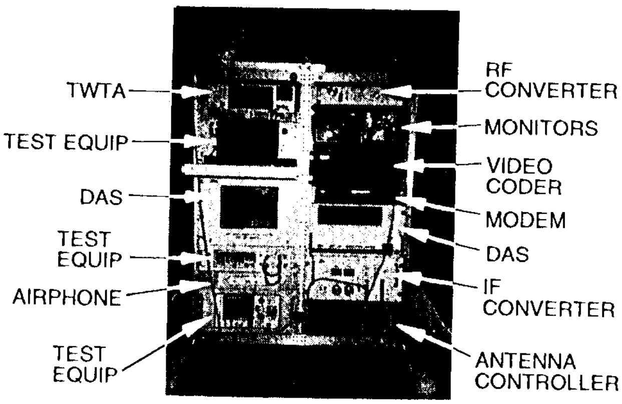

Figure 13 Equipment Rack in KAO C-141

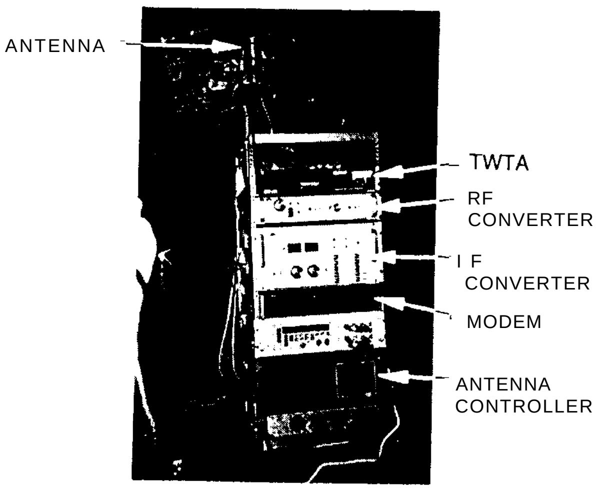

Figure 14 Equipment Rack in Rockwell/Collins Saberliner 50